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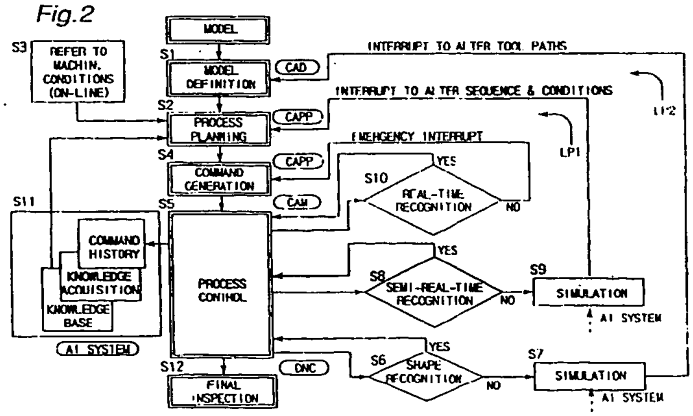
(54) Method of and apparatus for finely machining a workpiece with numerical control having a computer-aided simulation function.

(57) A machining program is prepared based on design data obtained by CAD and machining conditions stored in advance in a data base, while machining status information is obtained from a machining site. Based on the machining program and the machining status information, a machining status is simulated in order to subsequently prepare machining commands required for appropriate NC control.

Fig.2



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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a method of and an apparatus for finely machining a workpiece using a numerical control having a computer-aided simulation function. The method and apparatus of the present invention are suited for machining a very small workpiece having a size less than, for example, one millimeter.

Description of Related Art

When cutting machining or electrical discharge machining is executed at an NC machining center, the conventional practice is such as shown in Fig. 9 wherein design data obtained by CAD are converted into machining information with CAM, and the machining information is then transmitted to the machining center in either an on-line mode or an off-line mode for subsequent machining.

However, if a very small workpiece having a size less than one millimeter is machined using the conventional method referred to above, even very small substances such as, for example, crystalline particles of the workpiece or impurities, which have hitherto caused no problems, may affect the progress of machining. For this reason, some problems arose in that only machining instructions under open-loop control cannot satisfactorily proceed the machining as designed in advance, in that the conventional visual observation is not possible due to the minute size of the shape, and in that no correction is possible in the course of the machining. Although it is conceivable that upon removal of the workpiece from the NC machine, the workpiece be measured for subsequent remachining, such measurement cannot be easily carried out because the working area is very small.

SUMMARY OF THE INVENTION

The present invention has been developed to overcome the above-described disadvantages.

It is accordingly an objective of the present invention to provide a method of finely machining a workpiece using a numerical control having a computer-aided simulation function, which method enables visual observation during machining even with respect to very small workpieces less than, for example, one millimeter, and can discover abnormal symptoms by sensing machining sounds.

Another objective of the present invention is to provide the method of the above-described type which can easily modify machining conditions even in the process of machining.

A further objective of the present invention is to provide an apparatus for effecting the method referred to above.

In accomplishing the above and other objectives, the method of the present invention is schematically depicted in Fig. 1 and is intended to simulate the machining status by checking and recognizing machining status information from a machining site where an NC machine works. The result of simulation is reflected in machining commands executed with CAM.

More specifically, the method of the present invention comprises the steps of: preparing a machining program based on design data obtained by CAD and machining conditions stored in advance in a data base; obtaining machining status information from a machining site; simulating a machining status based on the machining program and the machining status information; preparing machining commands based on the machining program and a result of simulation; and executing an NC control based on the machining commands.

In preparing the machining program, it is preferred that the machining status information from the machining site is referred to. Also, it is preferable to minimize the excess thickness that requires further machining by referring to at least one of tool shape information employed as one of the machining conditions and 2.5- or 3-dimensional information indicative of the shape of the workpiece during machining.

Advantageously, the method of the present invention further comprises the step of diagnosing abnormal conditions based on the machining status information or the step of reshaping a machine tool based on the machining status information obtained from the machining site.

The machining status information includes at least one of sound information obtained from the machining site, information indicative of a drive current required to drive an NC machine, information indicative of the shape of the workpiece, and information indicative of the shape of the machine tool.

The apparatus of the present invention comprises a machine tool for machining a workpiece, a drive means for driving the machine tool, an NC control means for controlling the drive means, a display and instruction means having a display function and an instruction function, and a control shell for collectively controlling the machine tool, the drive means, the NC control means, and the display and instruction means. The display and instruction means selectively displays design data obtained by CAD, machining conditions, a machining program, machining status information obtained at the machining site, a result of simulation executed by the control shell, and instructions given

to the control shell.

Conveniently, the control shell is a multitasking one having a task of converting the design data obtained by CAD into NC control information, a task of referring to machining condition information stored in advance in a data base, and a task of preparing the machining program based on the machining condition information and the NC control information. The multitasking control shell also has a task of obtaining the machining status information from the machining site, a task of simulating a machining status based on the machining status information and the machining program, a task of preparing machining commands required for NC control based on a result of simulation and the machining program, and a task of controlling the drive means in accordance with the machining commands.

Conveniently, the control shell further has a task of diagnosing abnormal conditions during machining based on the machining status information.

Advantageously, the apparatus comprises a reshaping means for reshaping the machine tool based on the machining status information obtained from the machining site.

Again advantageously, the apparatus further comprises at least one of a sound monitor for detecting sound information at the machining site, an ammeter for obtaining drive current information of the drive means, and a shape recognition means for obtaining shape information indicative of at least one of the workpiece and the machine tool. The shape recognition means may be a video camera, a laser microscope, a 3-dimensional digitizer or the like.

The machining to which the present invention is applied is such as, for example, cutting machining or electrical discharge machining.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objectives and features of the present invention will become more apparent from the following description of a preferred embodiment thereof with reference to the accompanying drawings, throughout which like parts are designated by like reference numerals, and wherein:

Fig. 1 is a schematic diagram explanatory of the method of the present invention;

Fig. 2 is a flowchart indicating the method of the present invention;

Fig. 3 is a schematic view indicating the machining processes of forming a rectangular opening;

Fig. 4 is a schematic vertical view of an NC machine of the present invention;

Fig. 5 is a perspective view of a workpiece and a machine tool;

Fig. 6A is a schematic diagram indicating the process of forming peripheral holes for the manufacture of an involute gear;

Fig. 6B is a schematic diagram indicating trace machining;

Fig. 6C is a schematic diagram indicating rough machining;

Fig. 6D is a schematic diagram indicating finish machining;

Fig. 7 is a schematic diagram indicating segmentation required to allow interrupt operations;

Fig. 8 is a block diagram indicating the operation of a control shell mounted in the NC machine of Fig. 4; and

Fig. 9 is a schematic diagram explanatory of a conventional method.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, there is shown in Fig. 2 a flowchart indicating a machining method according to the present invention. As is the case with the conventional method, a drawing is prepared with CAD, and design data indicative of a solid Figure obtained by CAD are converted by CAM into machining commands required for working a machine tool, which commands are in turn introduced into an NC system of a machining apparatus.

More specifically, as shown in the flowchart of Fig. 2, based on a drawing, image or the like indicative of the profile of a desired target object, the shape into which a workpiece is to be eventually machined is prepared at step S1 using a shape preparing function of CAD. Although this process is generally interactively executed, information of a given format can be fetched from any other CAD systems via an interface. Other shapes during machining are also prepared at step S1.

At step S2, the process planning which includes the machining sequence and machining conditions is set. In the case of forming a round hole or a slit, setting is carried out for each machining. On the other hand, in the case of forming an object having a 2.5-dimensional shape by machining, individual wire frame elements indicative of contour lines thereof are looped for continuity and directivity required for subsequent machining and are segmented to allow interruption (segmentation).

Although a machining program is prepared by setting appropriate tool paths according to the size of a machine tool such as, for example, an electrode, the machining conditions stored in a data base can be referred to at step S3. It is to be noted here that the machining conditions used throughout this specification mean predetermined conditions such as, for example, the shape of the machine

tool, machining speed, depth of cut, and the like.

In the process planning, it is preferred that the setting be carried out so as to minimize the excess thickness that requires further machining by referring to information on the tool shape employed as one of the machining conditions or 2.5- or 3-dimensional information on the shape of the workpiece or tool during machining. By way of example, as shown in Fig. 3 indicating machining processes of forming a rectangular opening, three round holes are first formed using a large-diameter tool. Then, four overlap points are machined using a middle-diameter tool and, finally, the still tugged internal surface of the opening is machined using a small-diameter tool.

Thereafter, based on the machining program prepared at step S2, machining commands required for driving the machine tool are generated at step S4, and drive control of the NC machine is executed at step S5.

At step S6, based on image information obtained at the machining site, a determination is made whether the shape of the workpiece recognized during machining is acceptable. If the shape of the workpiece is within the permissible range, the control of step S5 is continued. In contrast, if the shape of the workpiece is not permissible, an interrupt processing is executed to alter the tool paths. More specifically, st step S7, the NC system fetches from an AI system (data base) information on the shape of a new machine tool that may be preferably used in place of the machine tool now used. Then, simulation is executed to know the result of machining with the new machine tool based on a new machining program obtained by setting appropriate tool paths according to the size of the new machine tool, and on the information indicative of the shape of the workpiece and that of the new machine tool. Whilst the result of the simulation is being confirmed by a display and instruction means, if it has been determined that a desired shape may be obtained, the procedure returns to step S1 at which the present shape of the workpiece is prepared, and steps S2 to S5 are again successively executed. The display and instruction means is discussed later.

At step S8, based on control information on the waveform of a control current for the NC machine and the like, the machining status is checked or recognized to determine whether the machining conditions such as, for example, the initially set machining speed, discharge voltage, capacity of a capacitance, machining sequence and the like are suited for machining. At the same time, based on sound information indicative of machining sounds at the machining site, image information of the machine tool and the like, a determination is made whether the machine tool should be reshaped or the locus of machining should be modified in compliance with wear of the machine tool. If no abnormality has been recognized at step S8, the procedure returns to step S5 to continue the machining process control, whereas if an abnormality has been recognized, the machining status or the locus of machining is appropriately modified, followed by step S9 at which machining simulation is executed. Thereafter, an interrupt processing required to alter the machining sequence or the machining conditions is executed, which processing includes an interrupt required for optimization of the machining speed and an interrupt required to comply with the wear of the machine tool. This interrupt processing causes the procedure to return to step S2 at which a new machining program is prepared, and steps S4 and S5 are again executed.

In executing the simulation above, the information on the aforementioned machining conditions can be referred to. According to the present invention, upon review of the simulation result, if the progress of machining differs from the desired one, the machining program is modified by again executing the procedure of loop LP1 or LP2 or by repeatedly executing it. When the machining commands are prepared, because the operator can visually observe the progress of machining from the simulation result, the machining commands are generally determined in consideration of the observation result so as to minimize the excess thickness of the workpiece after the machining.

At step S10, recognition of the machining status is executed on real-time basis as to whether a serious situation such as damage to the machine tool occurs that requires interruption of the machining operation. If no abnormality has been confirmed, the machining process control is continued. In contrast, if an abnormality has been confirmed, an emergency interrupt processing is executed, and new machining commands such as, for example, a control suspension command are prepared.

At step S11, the control data used to control the machining process of step S5 are sent to the AI system and stored therein as process history information. By analyzing this process history information, rules relating to the machining process control can be acquired as knowledge data in which they are represented by "if-then-else" format, thus building up a knowledge data base. Preparation of a new machining program and simulation are executed at step S2 and at step S7 or S9, respectively, by making the knowledge base run on an AI inference system. This knowledge base is also used as reference information when the operator prepares or modifies machining programs.

If the machining status is acceptable, the machining operation is suspended, and the procedure advances to step S12 at which the finished object

is inspected.

Although not shown, the machining method of the present invention also includes the process of reshaping the machine tool, like ordinary machining methods. In this process, with reference to the machining status information obtained from the machining site and, particularly, to shape information of the workpiece and/or machine tool or control information indicative of the waveform of an electric current and the like, reshaping of the machine tool is executed.

Fig. 4 depicts an NC machine according to the present invention. This NC machine comprises a drive table 1 capable of moving in the X- and Y-directions, an electrical discharge machine 2, a cylindrical electrode 22 employed as a machine tool for machining a workpiece A placed on the drive table 1, and a drive means 21 capable of moving in the Z-direction to drive the cylindrical electrode 22. Two 3-dimensional digitizers 3 and 4 are mounted on the drive table 1 to inspect the cylindrical electrode 22 and the workpiece A, respectively. A dressing jig 5 is mounted also on the drive table 1 to reshape the cylindrical electrode 22 based on the machining status information obtained from the machining site. A sound monitor 8 for detecting sound information at the machining site is disposed below the workpiece A.

The NC machine also comprises an engineering workstation (EWS) 6 employed as the display and instruction means referred to above, and a control means 7 accommodating a control shell for collectively controlling all the elements of the NC machine. The control means 7 also accommodates an ammeter 9 for obtaining drive current information of the electrical discharge machine 2. The display and instruction means 6 has an instruction function in addition to a display function. Because of this, the display and instruction means 6 is capable of displaying CAD data, the machining conditions, the machining program, the machining site information, and the result of simulation, and is also capable of giving instructions to the control shell. The display and instruction means 6 may be a personal computer.

As shown in Fig. 5, when the workpiece A placed on the drive table 1 is to be machined into a hemispherical configuration, a pulse-shaped discharge voltage is applied between the workpiece A and the cylindrical electrode 22. While the drive table 1 is being moved in the X-and Y-directions, the drive means 21 drives the cylindrical electrode 22 to rotate and move in the Z-direction, thereby moving the cylindrical electrode 22 in a direction indicated by D to accomplish a desired machining.

Specific machining processes of making a tiny involute gear having a pitch circle diameter of 0.30 mm and twelve teeth are explained hereinafter with reference to Figs. 6A to 6D.

A final shape g into which a workpiece A is to be machined and a plurality of, for example three, desired shapes as shown in Figs. 6A to 6C in the course of machining are initially prepared. Based on the shapes prepared, a machining program and machining commands are prepared.

The workpiece A is then placed on the drive table 1, and a cylindrical electrode 22 having a diameter of 200 microns is mounted on the drive means 21 for subsequent drilling of a plurality of circularly arrayed holes shown in Fig. 6A. More specifically, in the machining process control, the cylindrical electrode 22 is placed in position so that its center may be located above a first position on a circle C having a diameter of 600 microns. The drive means 21 then drives the cylindrical electrode 22 to move downwards while rotating it, thereby forming a first hole c1 having a diameter of 200 microns at the first position. Thereafter, the drive means 21 drives the cylindrical electrode 22 to move upwards, and the workpiece A together with the drive table 1 is moved horizontally so that the cylindrical electrode 22 may be located above a second position on the circle C spaced 30° from the first position. A second hole c2 is then formed by moving the cylindrical electrode 22 downwards. The same operation referred to above is repeated twelve times until the drilling process shown in Fig. 6A is completed during which the plurality of circularly arrayed holes c1 to c12 are formed along the circle C.

Because these holes c1 to c12 form an annular groove having tugged vertical internal surfaces, the cylindrical electrode 22 is gradually rotated along the annular groove while being rotated on its own axis after the twelfth hole c12 has been formed, thereby forming an annular groove G having smooth vertical internal surfaces and a width of 200 microns, as shown in Fig. 6B (trace machining).

The trace machining is followed by a rough machining shown in Fig. 6C in which upon replacement of the cylindrical electrode, a new cylindrical electrode 22 having a diameter of 50 microns is moved along a programmed machining locus L1 so that the final shape g of the intended involute gear may have an excess thickness. In a subsequent finish machining shown in Fig. 6D, upon replacement of the cylindrical electrode, a cylindrical electrode 22 having a diameter of 20 microns is moved along a programmed machining locus L2 until the intended involute gear is obtained.

It is to be noted here that, as shown in Fig. 7, the final shape g of the involute gear is made up of a plurality of continuous ware frame elements, each of which is divided into a plurality of segments to permit an interrupt processing for each segment. In the machining processes shown in Figs. 6A to 6D,

recognition of the shapes during machining (step S6 in Fig. 2) and recognition of the machining status (steps S8 and S10 in Fig. 2) are executed. As occasion demands, simulations (steps S7 and S9 in Fig. 2) and associated interrupt processings are executed.

It is also to be noted that all the processes can be sequentially automatically executed by executing the electrode reshaping process prior to each machining operation.

The involute gear thus obtained has a machining accuracy of ±0.5 μm and the machining time thereof is reduced to about one tenth compared with the conventional method.

The control shell is a multitasking one having, as shown in Fig. 8, a task 11 of converting the design data obtained by CAD into information required for NC control, a task 12 of referring to the machining condition information stored in advance in the data base, and a task 13 of preparing the machining program based on the machining condition information and the NC control information converted. The control shell also has tasks 14a, 14b and 14c of obtaining the machining status information at the machining site, a task 15 of simulating the machining status based on the machining status information and the machining program prepared, a task 16 of preparing machining commands for NC control based on the result of simulation and the machining program, a task 17 of controlling the drive means in compliance with the machining commands, and a task 18 of diagnosing abnormal conditions during machining based on the machining status information.

In order to executes the tasks 14a, 14b and 14c, the NC machine is provided, as discussed previously, with the two 3-dimensional digitizers 3 and 4 for obtaining shape information of the cylindrical electrode 22 and the workpiece A, respectively, the ammeter 9 for obtaining drive current information of the electrical discharge machine 2, and the sound monitor 8 for detecting sound information at the machining site. The 3-dimensional digitizers 3 and 4 may be replaced by video cameras, laser microscopes, or the like.

As is clear from the above, according to the present invention, because fine machining is carried out with a numerical control having a computer-aided simulation function, the progress of machining can be visually observed even with respect to very small workpieces having a size less than one millimeter, and the machining processes can be easily modified in the course of machining. Also, the progress of machining can be known from machining sounds, if necessary. Because of this, the method and apparatus of the present invention enable the operator to appropriately judge the degree of progress of machining, and to advance the machining while teaching him, thus greatly enhancing the accuracy of machining.

As a result, the method and apparatus of the present invention bring about the following effects:

(a) Even if a change in the progress of machining occurs under the influence of very small substances such as, for example, crystalline particles of the workpiece or impurities, it can be readily modified.

(b) The machining can be advanced so as not to cause any changes in the machining status.

(c) The most advantageous machining method in respect to time and cost can be designed.

In addition to these effects, the operator can grasp the progress of machining with reference to image information or, in some cases, sound information. This implies that the method and apparatus of the present invention provide the operator with a desired working atmosphere that allows interactive processings between the operator and the machining apparatus.

Although the present invention has been fully described by way of examples with reference to the accompanying drawings, it is to be noted here that various changes and modifications will be apparent to those skilled in the art. Therefore, unless such changes and modifications otherwise depart from the spirit and scope of the present invention, they should be construed as being included therein.

Claims

1. A method of finely machining a workpiece (A) with a numerical control having a computer-aided simulation function, said method comprising the steps of:

   preparing a machining program based on design data obtained by CAD and machining conditions stored in advance in a data base;

   obtaining machining status information from a machining site;

   simulating a machining status based on the machining program and the machining status information;

   preparing machining commands based on the machining program and a result of simulation; and

   executing an NC control based on the machining commands.

2. The method according to claim 1, wherein the machining status information from the machining site is referred to in preparing the machining program.

3. The method according to claim 2, wherein the machining program is prepared so as to mini-

mize the excess thickness that requires further machining by referring to at least one of tool shape information employed as one of the machining conditions and 2.5-dimensional information indicative of the shape of the workpiece (A) during machining.

4. The method according to claim 2, wherein the machining program is prepared so as to minimize the excess thickness that requires further machining by referring to at least one of tool shape information employed as one of the machining conditions and 3-dimensional information indicative of the shape of the workpiece (A) during machining.

5. The method according to claim 1, and further comprising the step of diagnosing abnormal conditions based on the machining status information.

6. The method according to claim 1, and further comprising the step of reshaping a machine tool (22) based on the machining status information obtained from the machining site.

7. The method according to claim 1, wherein the machining status information includes at least one of sound information at the machining site, information indicative of a drive current required to drive an NC machine (2), information indicative of the shape of the workpiece (A), and information indicative of the shape of the machine tool (22).

8. An apparatus for finely machining a workpiece (A) with a numerical control having a computer-aided simulation function, said apparatus comprising:

a machine tool (22) for machining a workpiece (A);

a drive means (21) for driving said machine tool (22);

an NC control means (7) for controlling said drive means (21);

a display and instruction means (6) having a display function and an instruction function; and

a control shell for collectively controlling said machine tool (22), said drive means (21), said NC control means (7), and said display and instruction means (6),

wherein said display and instruction means (6) selectively displays design data obtained by CAD, machining conditions, a machining program, machining status information obtained at a machining site, a result of simulation executed by said control shell, and instructions given to said control shell.

9. The apparatus according to claim 8, wherein said control shell is a multitasking control shell having a task of converting the design data obtained by CAD into NC control information, a task of referring to machining condition information stored in advance in a data base, a task of preparing the machining program based on the machining condition information and the NC control information, a task of obtaining the machining status information from the machining site, a task of simulating a machining status based on the machining status information and the machining program, a task of preparing machining commands required for NC control based on a result of simulation and the machining program, and a task of controlling said drive means (21) in accordance with the machining commands.

10. The apparatus according to claim 9, wherein said control shell has a task of diagnosing abnormal conditions during machining based on the machining status information.

11. The apparatus according to claim 8, and further comprising a reshaping means (5) for reshaping said machine tool (22) based on the machining status information obtained from the machining site.

12. The apparatus according to claim 8, and further comprising at least one of a sound monitor (8) for detecting sound information at the machining site, an ammeter (9) for obtaining drive current information of said drive means (22), and a shape recognition means (3, 4) for obtaining shape information indicative of at least one of said workpiece (A) and said machine tool (22).

Fig.1

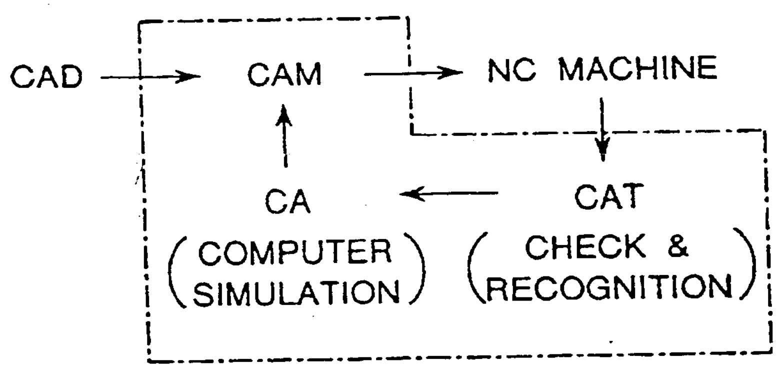

CAD
CAM
NC MACHINE
CA
(COMPUTER SIMULATION)
CAT
(CHECK & RECOGNITION)

Fig.2

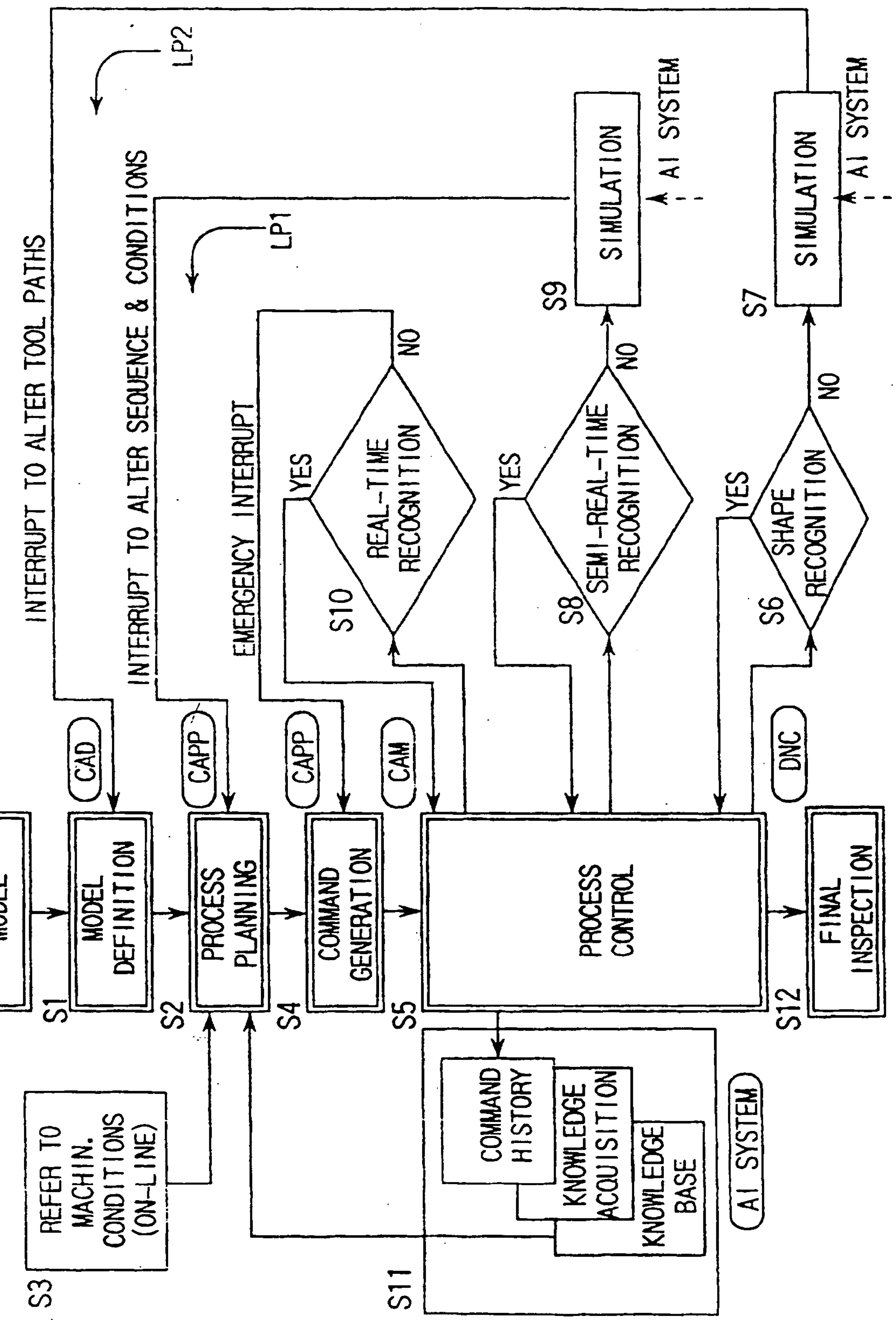

MODEL
S1
MODEL DEFINITION
CAD
S2
PROCESS PLANNING
CAPP
S3
REFER TO MACHIN. CONDITIONS (ON-LINE)
S4
COMMAND GENERATION
CAPP
S5
PROCESS CONTROL
CAM
DNC
S12
FINAL INSPECTION
S11
COMMAND HISTORY
KNOWLEDGE ACQUISITION
KNOWLEDGE BASE
AI SYSTEM
S10
REAL-TIME RECOGNITION
YES
NO
EMERGENCY INTERRUPT
S8
SEMI-REAL-TIME RECOGNITION
YES
NO
S9
SIMULATION
AI SYSTEM
S6
SHAPE RECOGNITION
YES
NO
S7
SIMULATION
AI SYSTEM
INTERRUPT TO ALTER SEQUENCE & CONDITIONS
LP1
INTERRUPT TO ALTER TOOL PATHS
LP2

Fig. 3

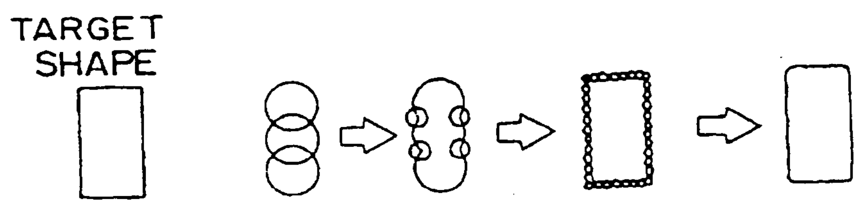


Fig. 7

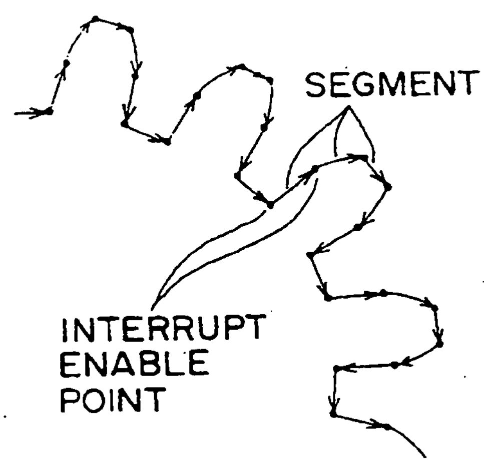
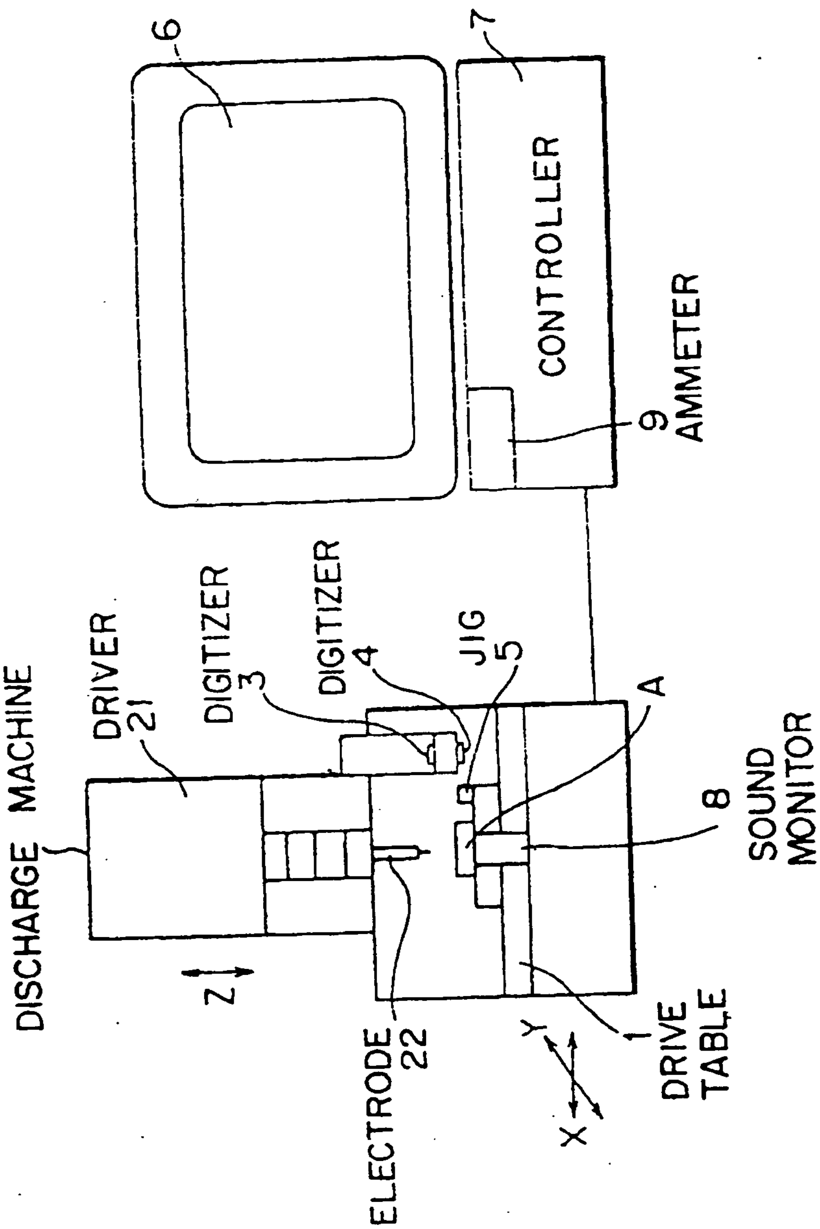


Fig. 4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DRIVER
21
DIGITIZER
3
DIGITIZER
4
JIG
5
A
6
7
CONTROLLER
9
AMMETER
8
SOUND
MONITOR
Z
ELECTRODE
22
X
Y
1
DRIVE
TABLE

Fig. 5

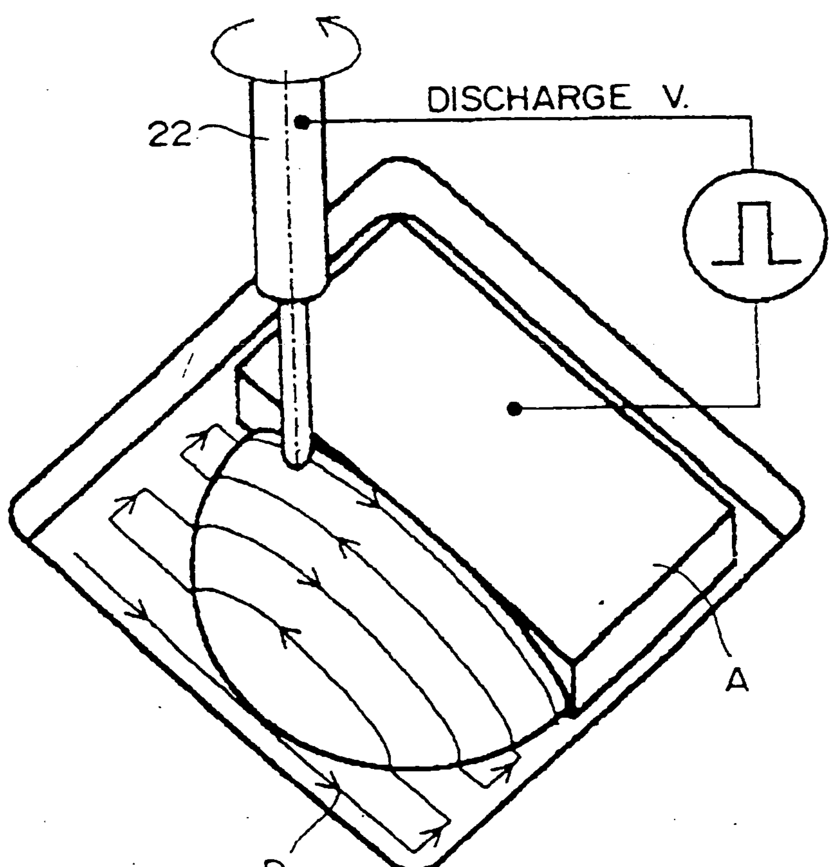


Fig. 6A

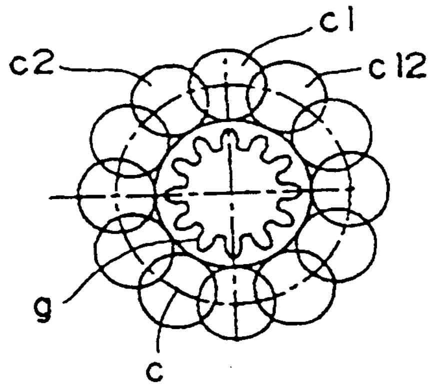


Fig. 6B

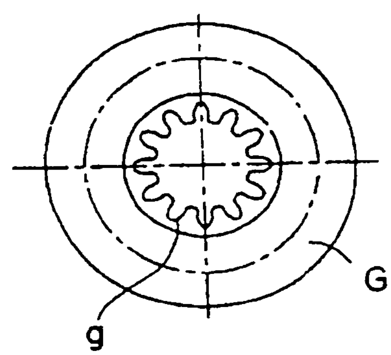


Fig. 6C

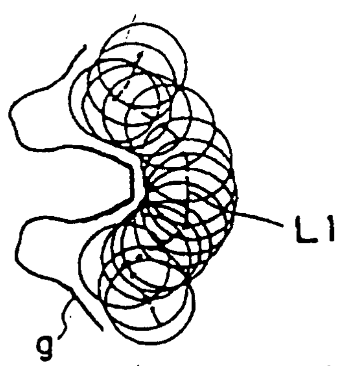


Fig. 6D

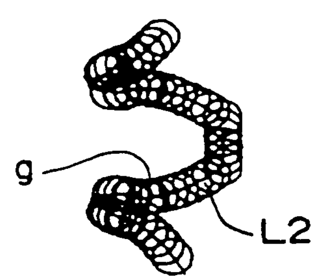
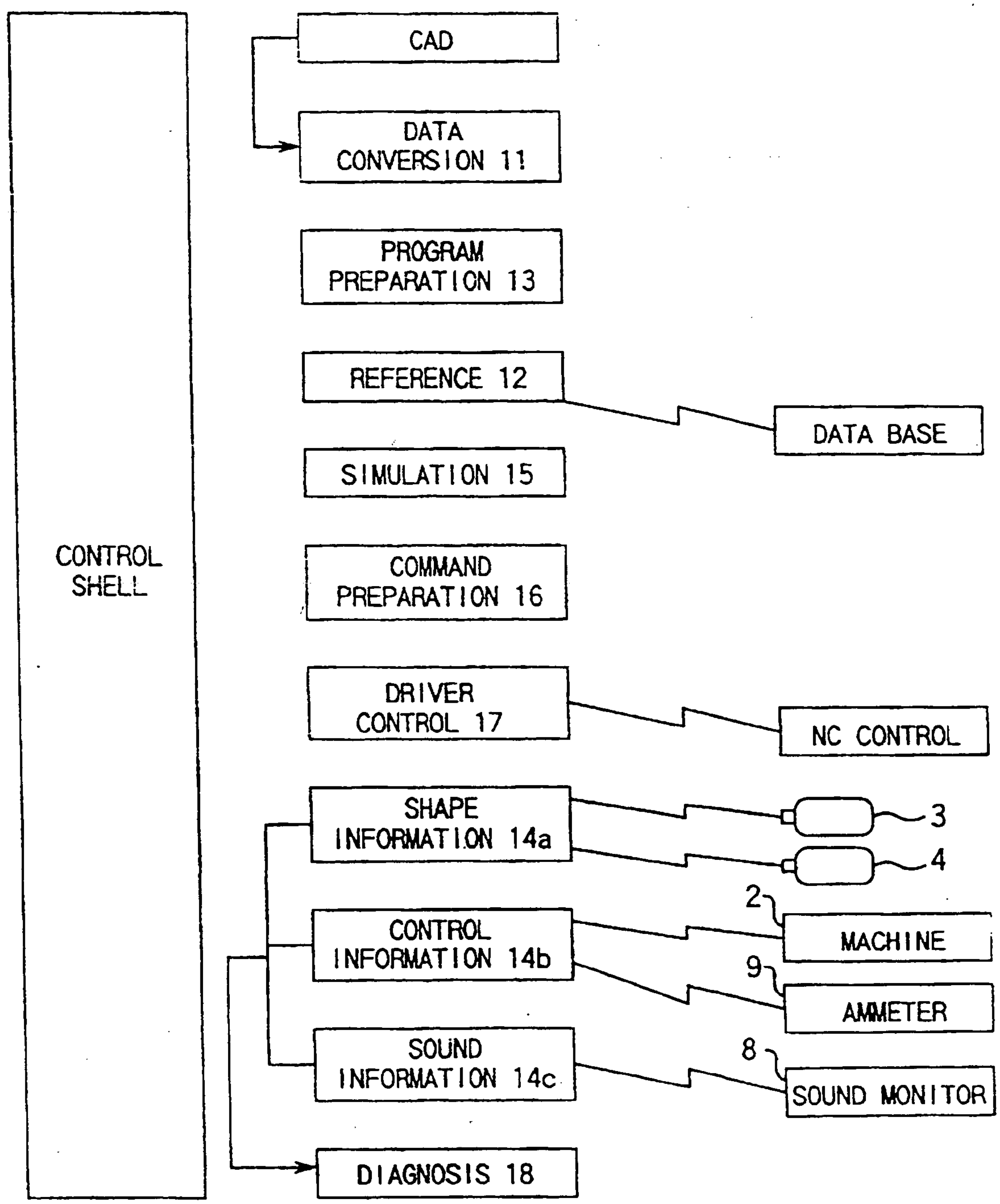


Fig.8


CONTROL SHELL
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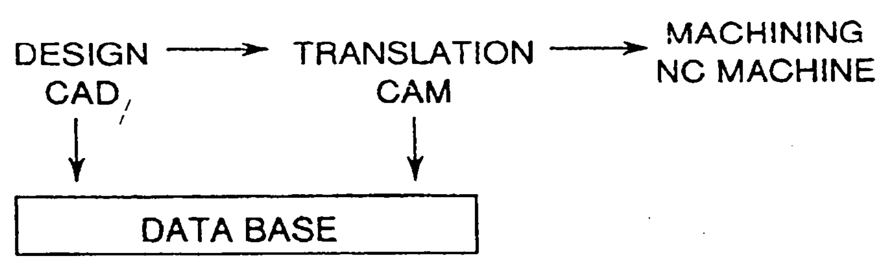
DATA CONVERSION 11
PROGRAM PREPARATION 13
REFERENCE 12
DATA BASE
SIMULATION 15
COMMAND PREPARATION 16
DRIVER CONTROL 17
NC CONTROL
SHAPE INFORMATION 14a
3
4
2
MACHINE
CONTROL INFORMATION 14b
9
AMMETER
SOUND INFORMATION 14c
8
SOUND MONITOR
DIAGNOSIS 18

Fig.9 PRIOR ART



European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 95103307.5

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 6)
A	DE - A - 4 105 096 (MITSUBISHI) * Fig. 2; claims 1-6 *	1-12	G 05 B 19/4069 G 05 B 17/00 B 23 Q 15/00
A	US - A - 5 122 966 (JANSEN et al.) * Abstract; claims 1-8 *	1-4,8,9	
A	EP - A - 0 513 369 (FANUL LTD.) * Fig. 1; claim 1 *	1,8,9	
			TECHNICAL FIELDS SEARCHED (Int. Cl.6)
			G 05 B G 06 F B 23 Q

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	30-05-1995	FUSSY

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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E : earlier patent document, but published on, or after the filing date
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